

Observation of suprathermal ions with Neutral Particle Analyzers during electron cyclotron heating in the TJ-II stellarator.

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Introduction

Plasmas in the TJ-II stellarator are created using two gyrotrons tuned to the second harmonic of the electron gyrofrequency. Additional heating can be applied using neutral beam injection or the plasma can be maintained with microwave power to produce a pure ECRH discharge. In the case of pure ECRH plasmas the majority ions are not directly heated by external sources rather by collisions with the hot electrons, hence their population distribution function is considered Maxwellian. The bulk ion temperature is clearly detached from the electron temperature, the usual value for the ion temperature is around 80 eV whereas the electron temperature is about 1 keV. Under such conditions the count rates in the high energy channels (> 1 keV) of the TJ-II neutral particle analyzers (NPA) are at the background level, indicating the absence of ions in the high energy tail. However, suprathermal ions have been found in TJ-II ECRH plasmas using spectroscopic methods [1].

In a recent experiment, we modulated the full power of one of the two gyrotrons to produce two clearly separate phases of the ECRH plasmas, one with full power, the other with half power. In addition, the radial position where the microwaves heat the plasma, was varied during the experiment. During the experiments the NPA was tuned to scan high energy ions. As a result, depending on the power deposition, signal levels above the normal background levels were detected in the high energy channels when full power was applied.

Experimental set-up

The heliac flexible TJ-II is a medium size stellarator ($R_0 = 1.5m$, $\langle a \rangle \leq 0.22m$, $B_0 = 1T$) situated in *Laboratorio Nacional de Fusión (Madrid, Spain)*. It has two gyrotrons operated at 53.2 GHz each with 250 kW maximum nominal power to create and maintain the plasma. The power of the gyrotron is carried to the plasma through two quasi-optical transmission lines, the waves are focused to the plasma with an steerable mirror inside the vacuum vessel. The final, in vacuum, steerable mirror has two angles settings that permit heating the plasma at different minor radius without inducing current [2].

The neutral particle analyser diagnostic used in this experiment is an Acord-12 [3] with a

single row of detectors. It scans hydrogen or deuterium atoms at 12 different energies, the energy set-up can be changed in a shot to shot basis, so it can scan the full range of energies in the plasma [4].

During the experiments performed here the plasma is started up with both gyrotrons, then one of them is modulated 100 % power by switching on and off during 40 ms. So parts of the discharge receive full power while the remaining time parts receive half power. The position of the mirror is changed between discharges to investigate the effect of the heating position on the production of suprathermal ions. Moreover, gas is puffed just in front of the line of sight of the NPAs to increase the amount of neutrals reaching the detectors. The integration time of the counters is fixed to 5 ms, to increase the signal/background ratio. Also the initial energy of the NPA is changed because the signal/background ratio is better in the low energy channels and rules out the possible effect of the electromagnetic radiation background.

Results

The main parameters for this experiment are plotted in figure 1. For instance, the heating scheme with gyrotron #1 modulated and gyrotron #2 running continuously is depicted in the top left of the figure. In bottom left the density (in $10^{19}m^{-3}$) and the H_α signal on the position of the NPA are shown. The density is almost constant along the discharge, whereas the H_α follows the programmed puffing, providing a qualitative measurement of the neutrals present in front of the NPA diagnostic. In the other two quadrants of the figure there is the raw signal of the NPA (Top: the first 6 low energy channels and bottom the 6 more energetic channels). In this case the lower energy channels correspond to an energy range of 200 to 600 eV and the high energy channels are looking at energies between 600 and 1500 eV.

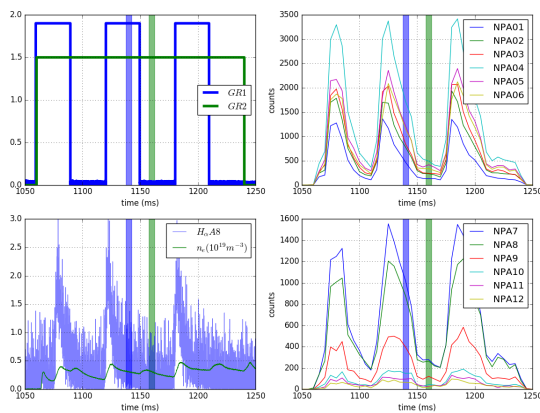


Figure 1: Main signals of the shot #42626.

$$\phi(E) \propto \int n_0 n_i(E) \langle \sigma v \rangle_{cx} dl \quad (1)$$

Equation 1 predicts that the flux of neutrals arriving the detector at a given energy is proportional to the density of neutrals and the density of ions with that energy in the line of sight of the diagnostic. The low energy NPA signals in figure 1 shows the same behaviour as the H_α signal that takes into account the neutrals in front of the NPA line of sight. So the

change of the NPA signal is considered to be mainly due to a change in neutral density. On the other hand the high energy signals do not follow it but drops when electron cyclotron heating is halved. This is an indication that the fall in signal level is caused by a drop in the ion density rather than a fall in neutral density because the rest of the parameters in equation 1 remains constant.

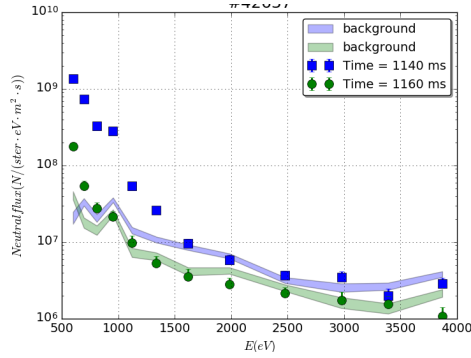


Figure 2: Neutral fluxes at two different times for the shot #42637. Background calculated as flux of equivalent shots with $E = 0$ eV in all NPA channels.

background electromagnetic signal is recorded.

Then the flux is calculated and the error is treated as before. The results are plotted as blue and green lines, depending on the time.

As can be seen in the case of the full ECH power the signal in the higher energetic channels is clearly separated from the background level while on the other case is not so clear.

In figure 3 we calculate the ratio between the flux at full power ($t = 1140$ ms) and half power ($t = 1160$ ms) for all the energies scanned in

Figure 2 shows the fluxes at two different times for shot #42637. In this shot the low energy limit was set to 600 eV, so only high energy ions were detected. The times chosen correspond to full ECH power ($t = 1140$ ms, blue vertical line in figure 1) and half ECH power ($t = 1160$ ms, green vertical line in figure 1). To calculate the errorbar in the plot we assume that counts follow Poisson statistics, so the error in the counts will be $N \pm \sqrt{N}$. We use the estimated error on the counts and propagate it on the formula used to calculate the flux to have a value for the flux error. To take into account possible background signal a shot with very similar plasma settings is considered but with the energy in each detector set to 0. Doing this a measure of the

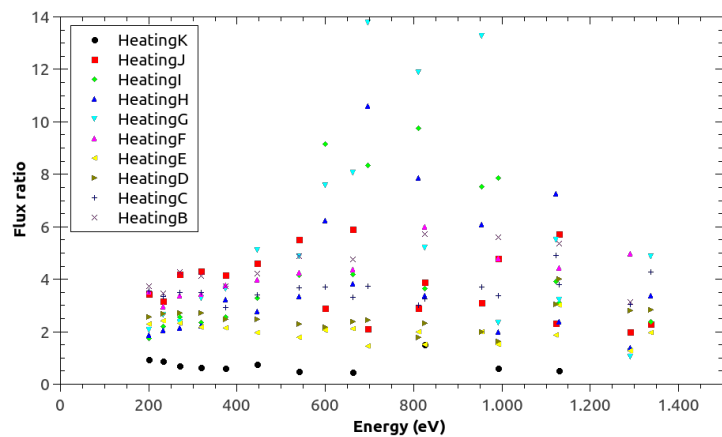


Figure 3: Ratio of neutral fluxes between full and half power heated plasma for the different heating schemes as a function of the energy.

each heating scheme (labeled from B to K). There is a clear increase of the ratio in the 600-1000 eV range, more evident for some of the heating schemes. The flux on the high energy channels depends strongly on the heating scheme. The only difference among the heating schemes is the position of the steerable mirror so we can conclude the generation of suprathermal ions depends on the heating position of the plasma.

Discussion

Usually in TJ-II ECR heated plasmas the signal in the NPA channels over 700 eV cannot be distinguished from the normal background signal. In the case of the experiments reported here there is a strong evidence of counts over background in the high energy channels when both gyrotrons are turned on.

The flux increase is very evident for a selected range of energies (600 - 1000 eV) and depends on the position of the heating. Typically TJ-II plasmas have a hollow density profile when heated only by ECR, that is the maximum of the density is not at the centre of the plasma.

One possible explanation to the generation of suprathermal ions is given by Gusakov in [5] and references therein. It suggests a parametric decay of the ECRH wave to other two waves, one of which heats the main plasma ions thereby generating the suprathermal ions. One requirement to the parametric decay is the existence of nonmonotonous density profile as is the case of TJ-II ECR heated plasmas. Also there is a power threshold to produce the two waves, that would explain the difference between one and two gyrotrons heating in the suprathermal ions generation. So the theory in [5] fits well with the results of the experiments reported here.

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References

- [1] D. Rapisarda, B. Zurro, V. Tribaldos, A. Baciero and TJ-II Team, *Plasma Physics and Controlled Fusion* **10**, 309 (2007)
- [2] J.M. Fontdecaba, A. Fernández, A. Tolkachev, A. Ros, A. Cappa, J.M. García-Regaña and G. Catalán, *Strong Microwaves: Sources and Applications* **2**, 419 (2009)
- [3] A. Izvozchikov, M.P. Petrov, S.Ya. Petrov, F.V. Chernyshev, and I.V. Shustov, *Sov. Phys. Tech. Phys.* **37**, 201 (1992)
- [4] J.M. Fontdecaba, S.Ya. Petrov, V.G. Nesenevich, A. Ros, F.V. Chernyshev, K.J. McCarthy and J.M. Barcala, *Review of Scientific Instruments* **85**, 11E803 (2014)
- [5] E.Z Gusakov and A. Yu. Popov *Plasma Phys. Control. Fusion* **60**, 025001 (2018)